Composite Materials Enable Lighter and More Effective Fire Support

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Enabling Technology for the Objective Force

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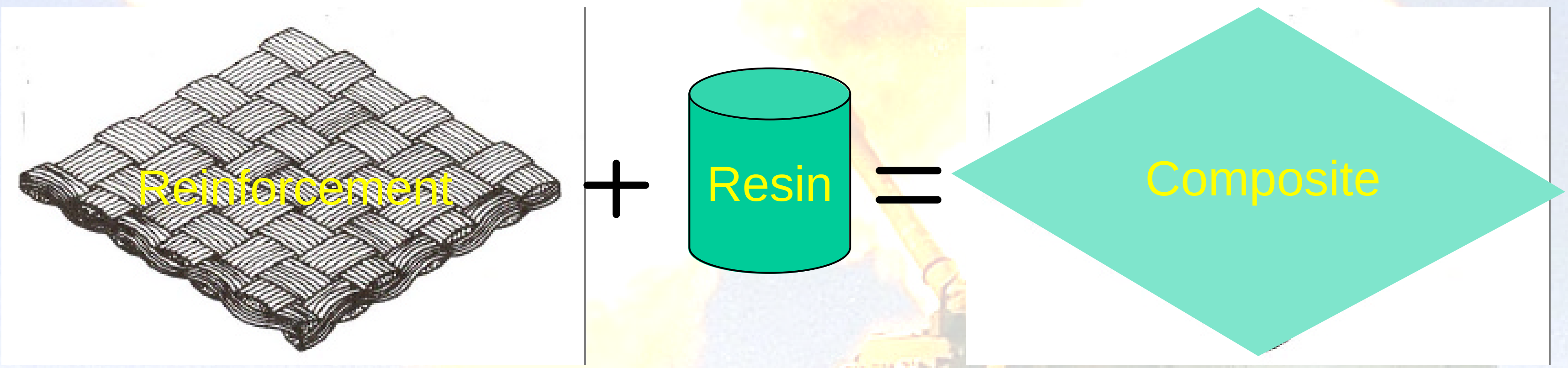
What Are Composite Materials?

A Composite is Any Heterogeneous Combination of Two or More Material Phases



Formulated To Obtain "Better" Performance

Than Individual Constituents

Usually Combining a "Reinforcement" with a "Matrix"

What Are Some Forms of Composites?

Example	***Constituents***
Wood	Cellulose Fiber in Lignin
Plywood	Cross-Laminated Veneers
Concrete	Steel & Rock in Cement
Fiberglass	Glass Fiber in Polyester
CRP	Carbon Fiber in Epoxy
MMC	SiC Fiber/Particles in Aluminum
CMC	SiC Whiskers in Al_2O_3
Damascus	Laminated Steel & Iron

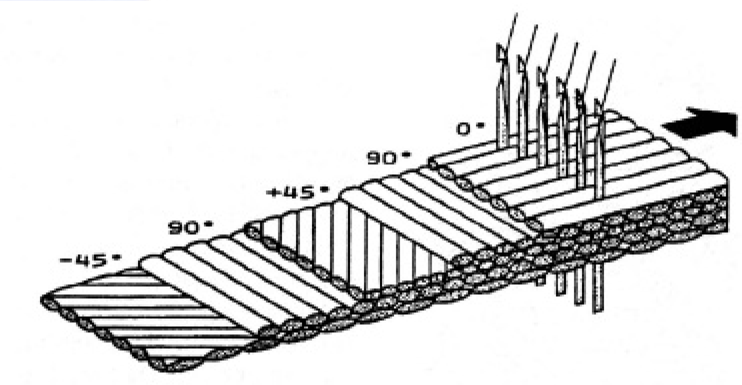
Why Would You Want Composites?

- **Superior Weight-Specific Strength & Stiffness**
- **Broad Flexibility in Strength & Stiffness Tailoring**
- **Can Introduce Significant Material Damping**
- **High Resistance to Fatigue Damage**
- **Chemical & Corrosion Resistance**
- **Very Low Thermal Expansion**
- **Very High Directional Thermal Conductivity**
- **Thermal & Radar Signature Control**
- **Easy to Make Very Complex Geometries**

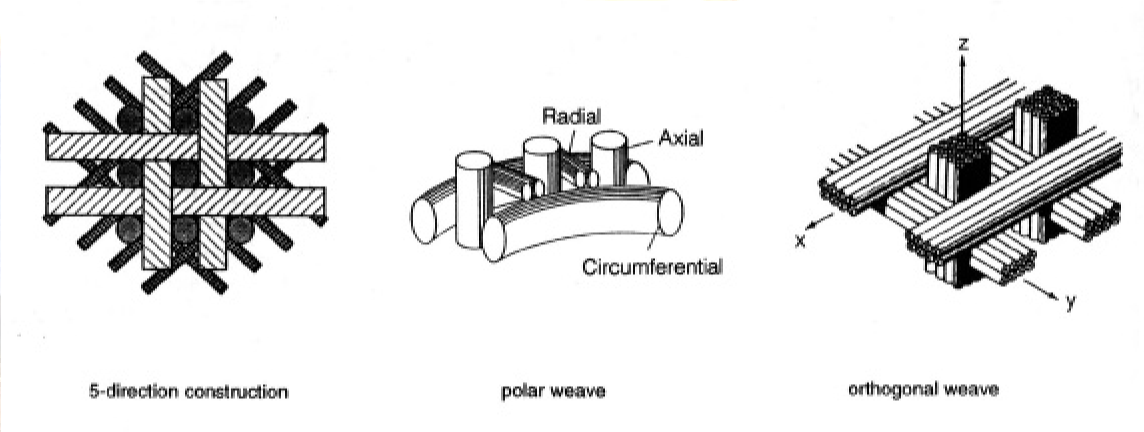
Typical Fiber Properties

Fiber Type	**Strength** **Modulus** (psi)	**Specific Gravity**	**Cost** $/lb.	**Comments**
E - Glass	500,000 10,000,000	2.58	0.70	Stable to >1100 F Good compression & shear
S2 - Glass	700,000 12,500,000	2.48	7 – 9	Stable to > 1400 F Good compression/shear
T1000 – Graphite	925,000 (+) 42,000,000	1.8	75	Extraordinary strengths
P100 - Graphite	350,000 110,000,000	2.2	90	Difficult to process, extraordinary stiffness
PANEX-33	500,000 33,000,000	1.75	7	Excellent Stiffness per $
Kevlar 49 - Aramid	410,000 16,000,000	1.45	25	Oxidation above 300F Low Shear/Bend Stress
Zylon - PBO	840,000 40,600,000	1.56	50 - 75	Sensitive to seawater, UV, as well as crimp
Spectra/Dyneema/Certran – High Modulus Polyethylene	400,000-500,000 16,000,000	0.97	25+	Creep, Transforms at ~ 250 F to low strength
Technora – Aramid	500,000 8,000,000	1.4+	25+	Stable to ~ 450 F, Less UV Sensitive
Vectran – Liquid Crystal Polymer	410,000 9,400,000	1.4	30	Better fatigue, bend, thermal, & moisture props. than aramids

Reinforcements Can be 1-D, 2-D, or 3-D



- Layers of Unidirectional Lamina
- Randomized 3-D Felts
- Layers of 2-D Fabric
- Stitched Assemblies of 2-D Layers
- Woven or “Lincoln Log” 3-D
- “Zero-Sum” Game for Total Reinf.

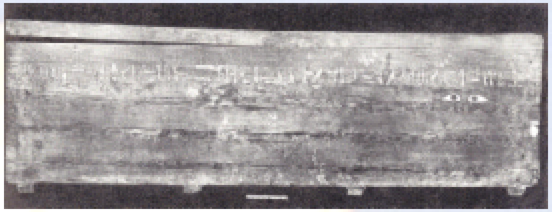


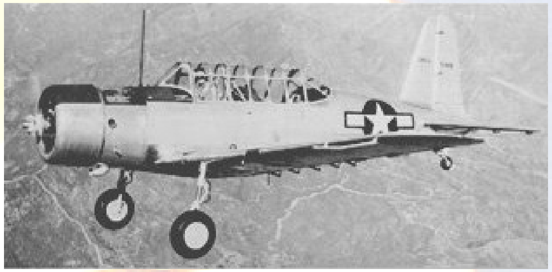
How Do Composites Differ from Metals?

- **Composite Behavior is Fundamentally Anisotropic**
- **Ratios Between "Strong" and "Weak" May be 100:1**
- **Essentially Infinite Combinations of Reinforcement, Matrix, and Architecture are Possible – *Corresponding Property Variations***
- **Fabrication Processes May Strongly Affect Properties for Similar/Identical Formulations**
- **Consequently, Design Allowables Not Well Defined**
  - Must "Proof" Each Distinct Composite Formulation
- **Composites Fail at Relatively Small Strains < 5%**
- **Composite Fabrication by "Addition" vs. "Subtraction"**

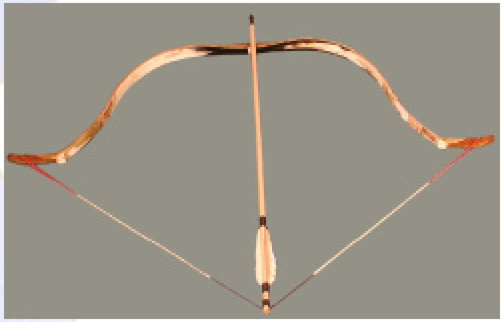
Brief History of Composite Materials

- Straw & Mud Bricks, < 2500 BC
- Plywood Sarcophagus, 1500 BC
- Horn/Wood/Sinew Bows, 800 BC
- Filled Concretes, 400 BC
- Laminated Iron, 500 AD
- “Damascus” Iron/Steel, 1500 AD
- Linen-Paper/Phenolic, 1920
- Fiberglass Radomes, 1940
- Fiberglass A/C Fuselage, 1944
- Boron & Carbon Fibers, 1960
- Polymeric “Superfibers”, 1970+

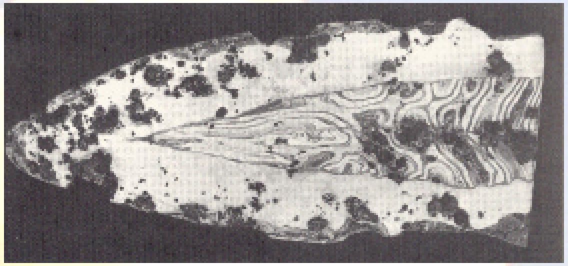




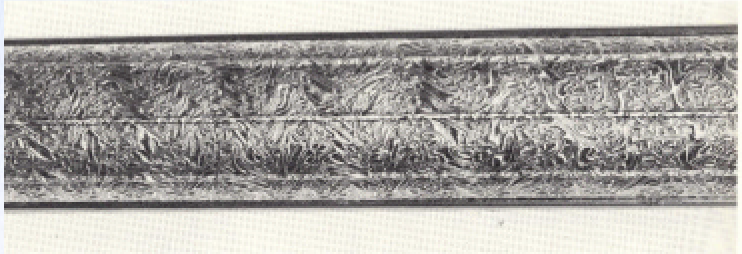
Weapons Have Long Used Laminated Composites



Tartar Bow, ca. 800 – 500 BC



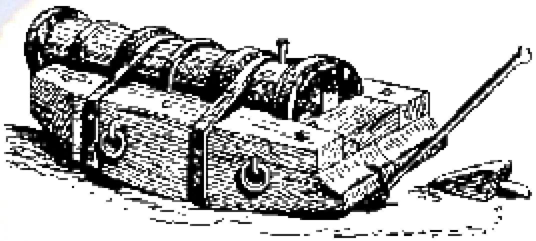
Frankish Sword Blade, ca. 500 AD



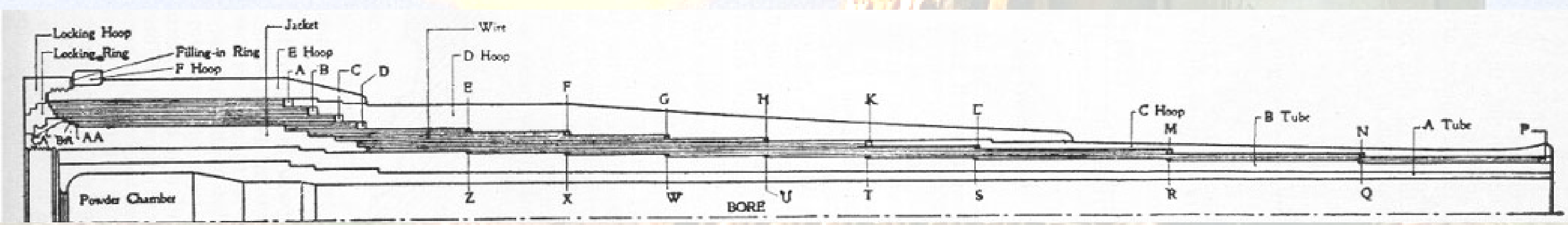
Damascus Gun Barrel, 1650 AD

Composite Armored Vehicle, 1993

Composites Have Been Used in Artillery for a Very Long Time



- **Hoop-Banded Gun Tubes Formed of Hammer-Welded Longitudinal Rods Were used in the Late 14th – Early 15th Centuries**
- **In the US Civil War, the 3” Ordnance Rifle was Fabricated by Diagonally Wrapping and Hammer-Welding Wrought Iron Strip**
- **In the 1880s-90s, Armstrong’s Process for Wire-Wrapped Gun Tubes was Adopted by Many, Including the USA – 16” M1919**



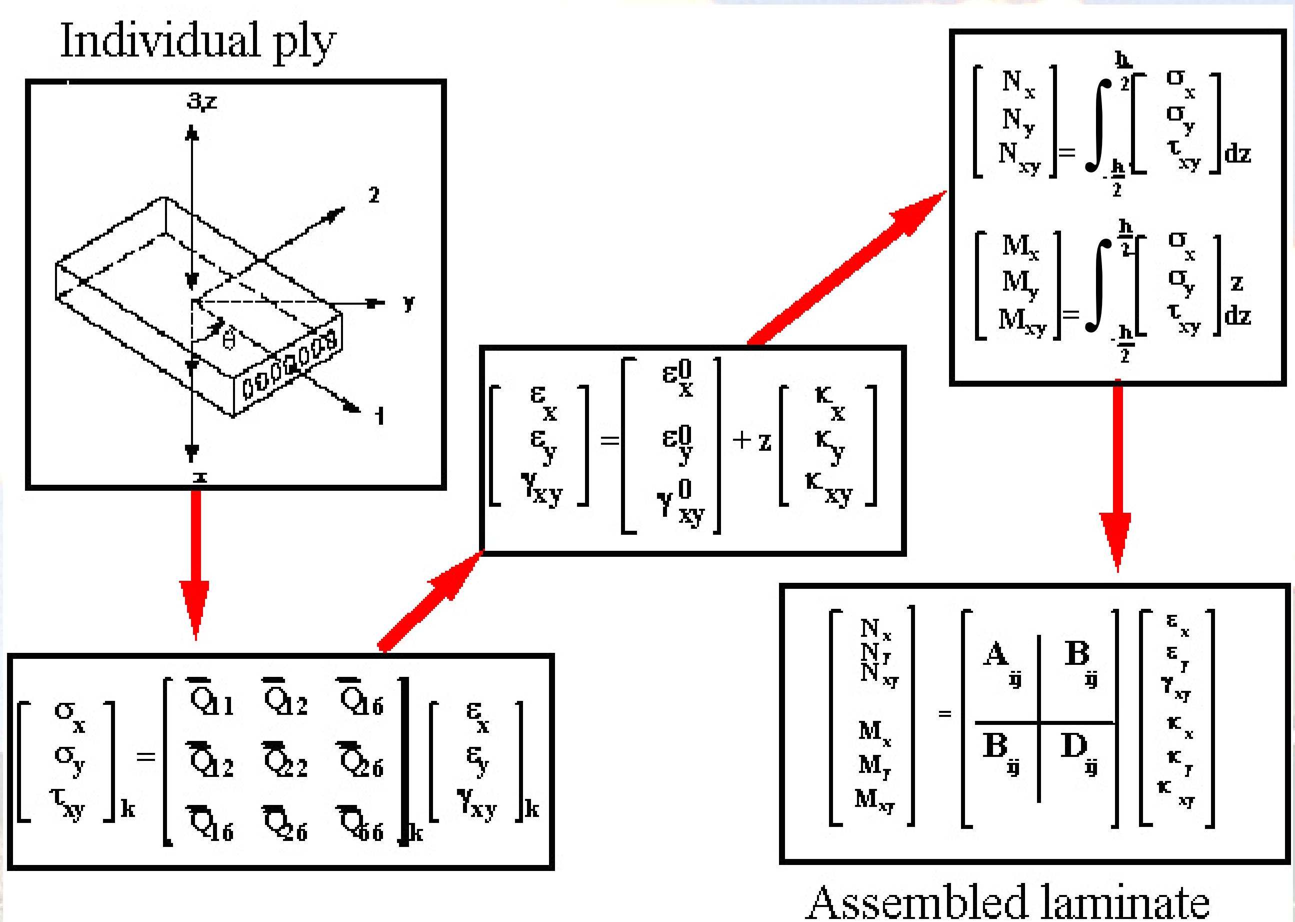
Opportunities and Pitfalls in Composite Design

- **Very High Strength (>500 ksi) and Stiffness (>50 Msi)**
- **Density Ranges from 0.060-0.090 pci (20-30% Steel)**
- **Can Place Strength/Stiffness only Where Needed**
- **Can Introduce Response Coupling (e.g. Bend/Twist)**
- **Can Achieve Very Low CTE (< 0 ppm/F)**

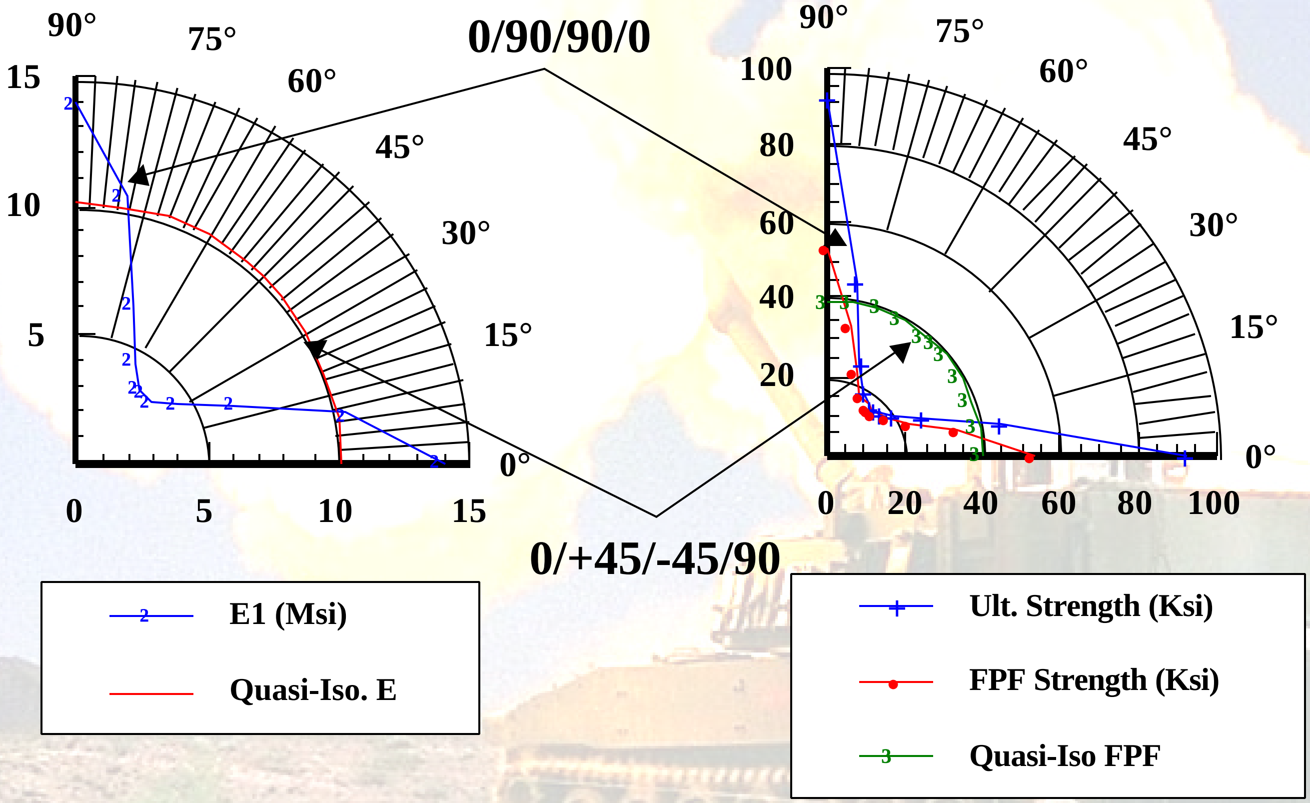
But

- **Very Low Interlaminar Strength & Conductivity**
- **Inspectability May be Problematical**
- **Design Analysis Must Consider Many Variables**

Analysis Builds Material Properties from Constituents



Stiffness & Strength Variations in Symmetric T300/5208 Epoxy Laminates



Rules of Thumb for Composite Design

- **Can Get up to 70% Fiber Volume Fraction: 1-D**
- **Can Get to 55 – 60% Fiber Volume Fraction: 2-D**
- **Strength & Stiffness Proportional to Fiber Volume**
  - Unidirectional ~ 60% - 70% of Fiber Properties
  - 0/90 ~ 30% in Principal Directions (60% x 50%)
  - Quasi-Isotropic (0/90/+45/-45) ~ 20% - 25%
  - Woven Constructions Less Stiff than Nonwovens, but Tough
- **There Will Always be at Least One Very Weak Direction in Laminated Composites ~ 5000psi**
- **Composites Almost Never Fail in Direct Tension**

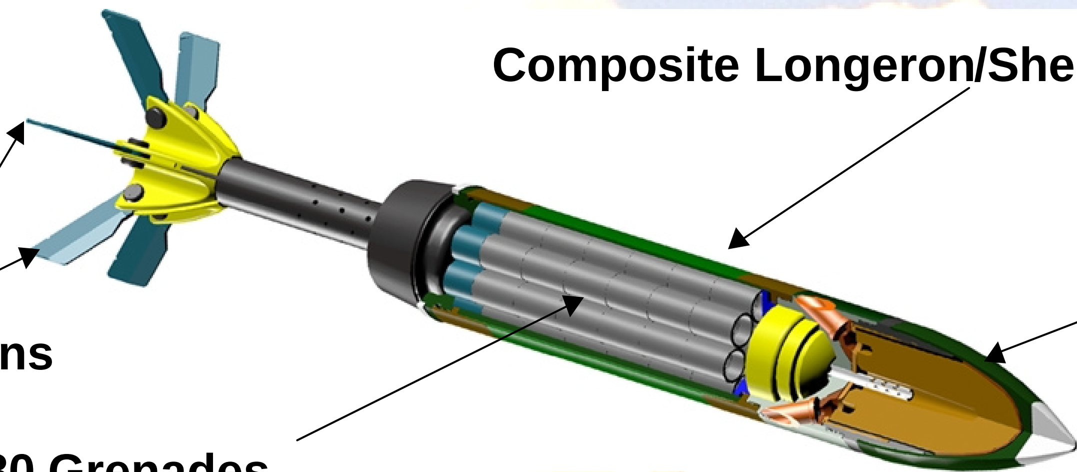
Critical Cost Tradeoffs Exist in Composite Manufacturing

- **Material Selection Drives Cost**
  - Strength-Dominated Designs Favor Glass - < $1/lb.
  - Stiffness Dominated Designs Favor Graphite - >$7/lb.
  - Resins Vary Widely in Cost & Performance
- **Processing Methods Vary in Cost & Capability**
  - RTM/VARTM – Complex Geometry, Modest Up Front & Recurring Cost
  - Pultrusion – Constant Section, High Tool & Very Low Recurring Cost
  - Press Forming – Formable Geometry, High Tool & Low Recurring Cost
  - Filament Winding – Axisymmetric Geometry, Modest Tooling
  - Tow/Tape Placement – Complex Geometry, High Facility & Recurring
  - Hand Layup – Complex Geometry, Lowest Tooling/Highest Labor Cost

Recent Applications of Composites to Ordnance and Protective Structures

- ***XM984 120 mm DPICM Mortar Cartridge***
  - Reduce Weight & Extend Range
  - Maximize Cargo Round Payload
  - Government/Industry Team Working Under a STO Program with Very Limited Tech Base Funding
    - US Army ARDEC, INTELLITEC, KCI, Talley, L3/BT Fuze
    - Achieved Milestone TRL 5
- ***Tactical and Sporting Small Arms Barrels***
  - Increased Tube Stiffness – to – Weight Ratio
  - Provide Exceptional Dimensional Stability
- ***AAAV Topside Backing Armor***
  - Improve Weight-Specific Ballistic Performance
  - Reduce Manufacturing Cost

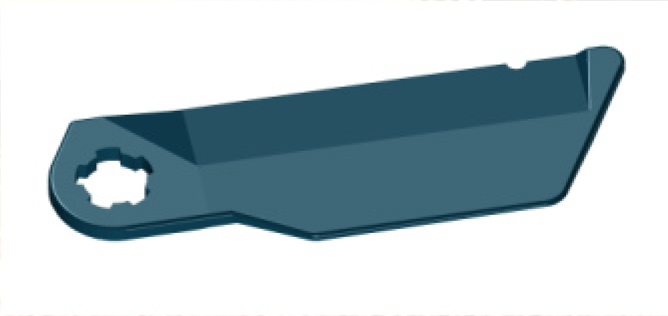
XM984 120 mm DPICM Mortar Cartridge



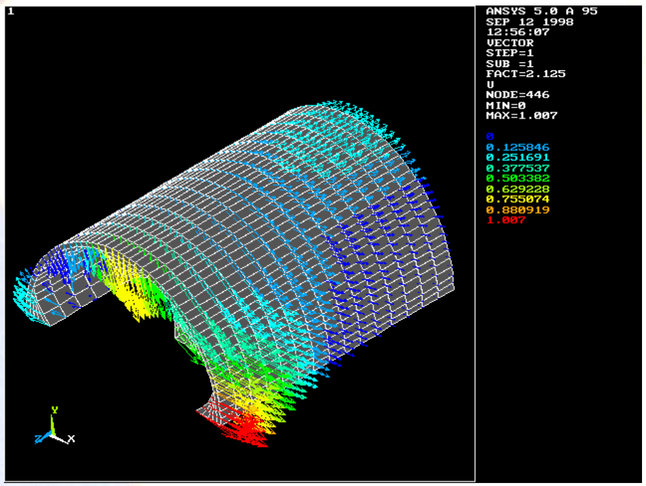
- **Composite Materials Enable XM984 Performance**
  - Saves 4.0 lb To Meet Total Round Weight of 33 Pounds
  - Reduces Cost by Net-Shape Molding with Highly Reproducible Processes & Components
  - Optimizes Fin Opening Times via Reduced Mass
  - Provides Damping for Fin/Boom to Minimize Excursions

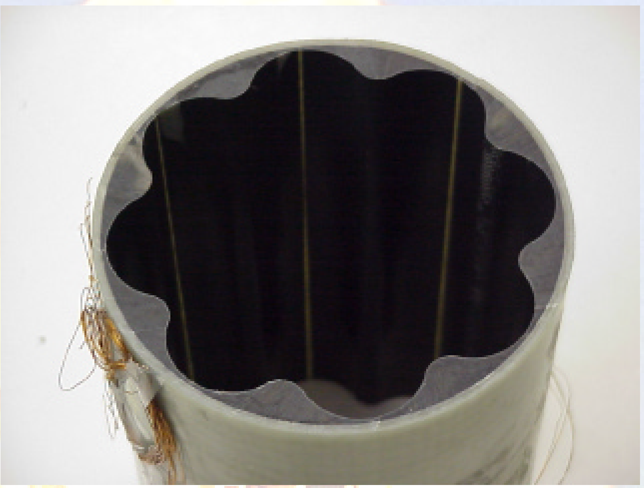
XM984 Moving to All-Composite Design

- Resin Transfer Molded Glass/Epoxy Nose with Bonded Ring
- Hybrid Glass Shell/Graphite Longeron RTM Midbody
- Hybrid Graphite Spar/Glass Skin Molded Fins



Extensive Analysis & Test Proves XM984 Composite Design

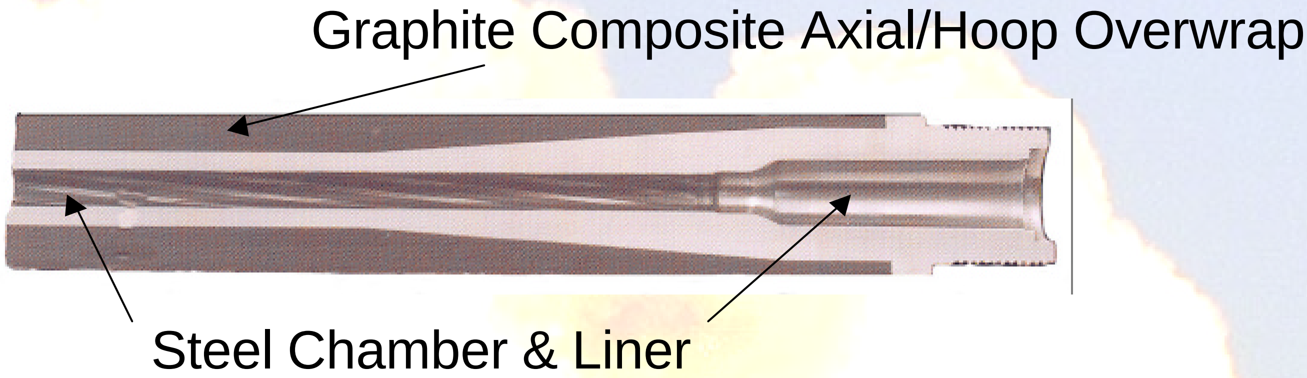




Operational Requirements Are Met

- – Setback Loads, 12,000 G
- – Rocket Motor Burn, 2500 psi
- – SubMunition Expulsion, 5000 psi
- – Handling Drop, 6.5 ft onto Steel

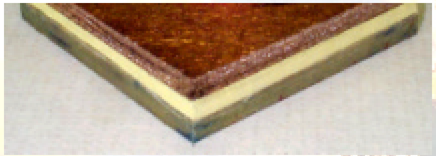
Tactical and Sporting Small Arms



- **Wide Range of Applications Have Been Evaluated**
  - Sporting & Sniper Rifles, 0.22 caliber, 7.62 mm, & 0.50 BMG
  - Lightweight 81 mm Mortar Tube
- **Near Zero CTE and High Stiffness Overwrap Minimize Deviations due to Temp. Variations**
- **But Low Radial Conductivity Slows Bore Cooling**
  - Need Cooling Augmentation for High Firing Rate

AAAV Topside Backing Armor

- **Existing Composite Solution Provides Good Fragment Protection, but Expensive**
- **Hybrid Multi-Fiber, Multi-Resin Pultruded Composite is both Lightweight and Cost-Effective**
  - Ballistic Performance Improved vs. S2-Glass/Phenolic
  - Continuous Pultrusion Processing Minimizes Cost



Composite Materials Provide Powerful Leverage for Future Applications

- Ultra-Strength Composites Minimize Wt. & Wall Thickness to Allow DARPA OOD Mine in XM984 Mortar Cargo Round,
- FCS 105 mm Cargo Round Enabled by High Strength Midbody Design in Composites,
- Novel Hybrid Composite/Tungsten Wire Configurations May Provide Advanced Earth Penetrators,
- Ultra-High Thermal Conductivity Pitch Graphite Composites Can Provide Passive Cooling for Gun Tubes,
- Filament Wound Composite Vessels Reduce Mass of Accumulators, Recoil Cylinders, Recuperators,
- Infusion Molded Composite Cradles, Stabilizers, Trails Can Reduce Weight and Cost with Superior Performance

Sources for Further Information
Questions??

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- **"Experimental Mechanics of Fiber-Reinforced Composite Materials", SESA Monograph No. 4, The Society for Experimental Stress Analysis, 1982.**
- **Journal of Composite Materials, Technomic/Sage Publishing Company.**
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- **The University of Delaware, *Center for Composite Materials*, www.ccm.udel.edu**